

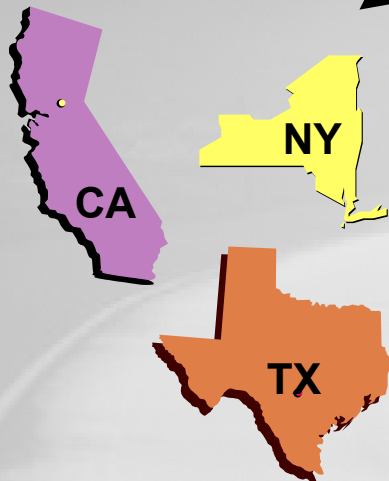
Processing, Transportation and Storage of LNG

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An LNG History Lesson

1997 BNL LNG Marketing Strategy



State Programs

- CALSTART
- USA Pro
- Lone Star
- EBA



Market/Technical Analyses

- BNL
- GLICC
- Vandor



Market Kits/User Guides

- GRI
- New Mexico State U.
- Battelle
- Acurex Environmental

The Five E's of NGVs

- **Energy Security:**
Fuel economy of 48.5 mpg and 10% alternative fuel will eliminate oil imports
- **Environment:**
All vehicles have to meet EPA's 2007 emission standards
- **Education:**
Training, outreach, tiger teams and codes & standards
- **Efficiency:**
80% well-to-engine efficiency with better than 37% engine efficiency
- **Economics:**
Business Case: Fuel cost, vehicle conversion cost, station cost and engine durability

Features of LNG & L/CNG

- **Increase driving range of 2.5 times over CNG is the main advantage of LNG**
- **LNG has the “use it or lose it” problem**
- **There is little technical risk with CNG – use it if there is a business case**
- **L/CNG is not in competition with CNG but offers additional refueling sites**

Choice between CNG and LNG is clear

High Fuel-Use Assumptions by Vehicle Segment

Vehicle Class	Annual Miles Traveled	Miles per Gallon	Gallons Consumer/Year
Automobile	12,000	30.0 GGE	400
Light-Duty Truck	16,000	16.0 GGE	1,000
Medium-Duty Truck (Class 3-5)	25,000	11.0 GGE	2,270
School Bus	12,500	3.0 GDE	4,170
Transit Bus	40,000	3.5 GDE	11,430
Heavy-Duty Truck (Class 6-8)	100,000	6.5 GDE	15,385

* GGE = Gallon gasoline equivalent

* GDE = Gallon diesel equivalent

The Dark Secret of LNG

What we like to have



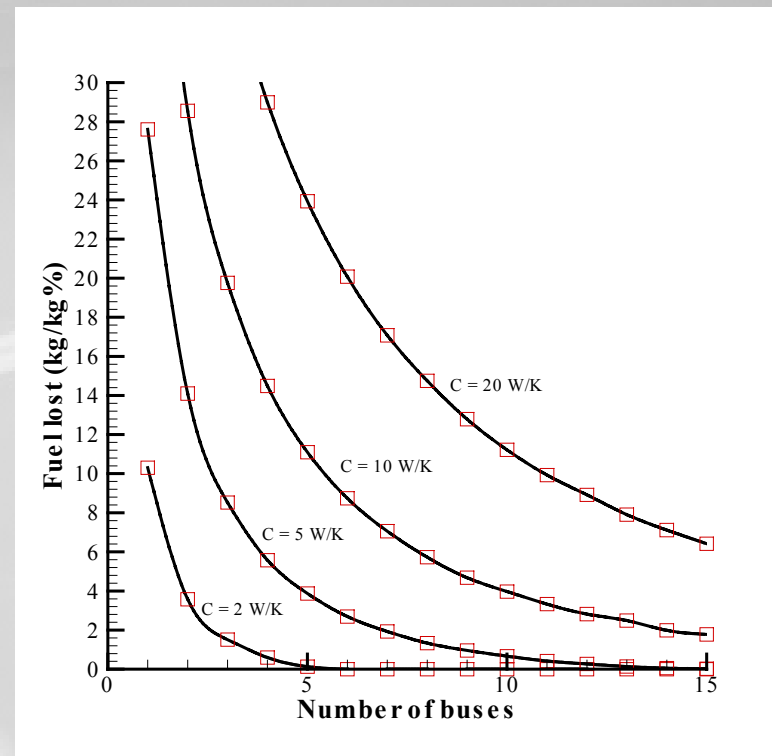
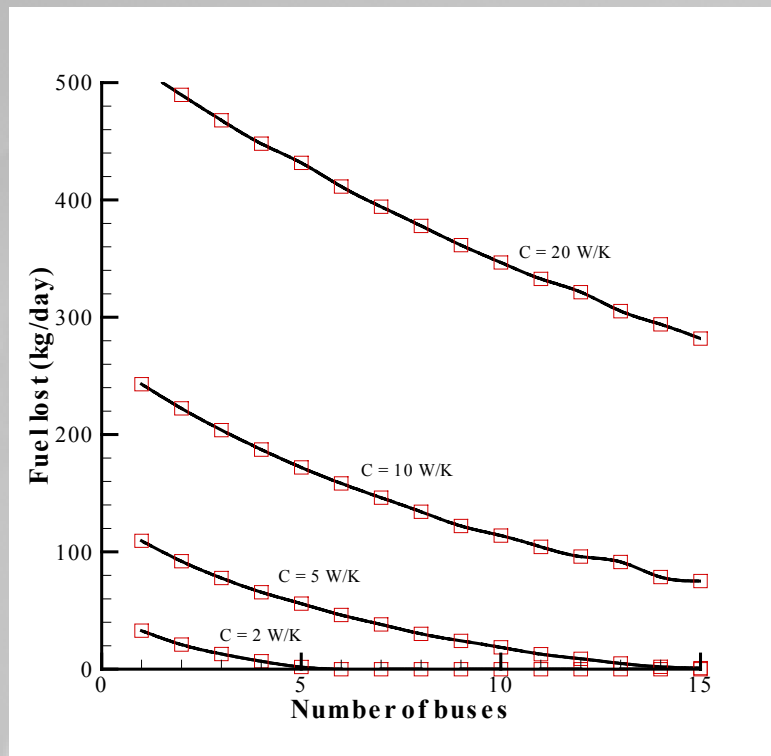
1.7 gal LNG per gallon Diesel

What is *really* happening



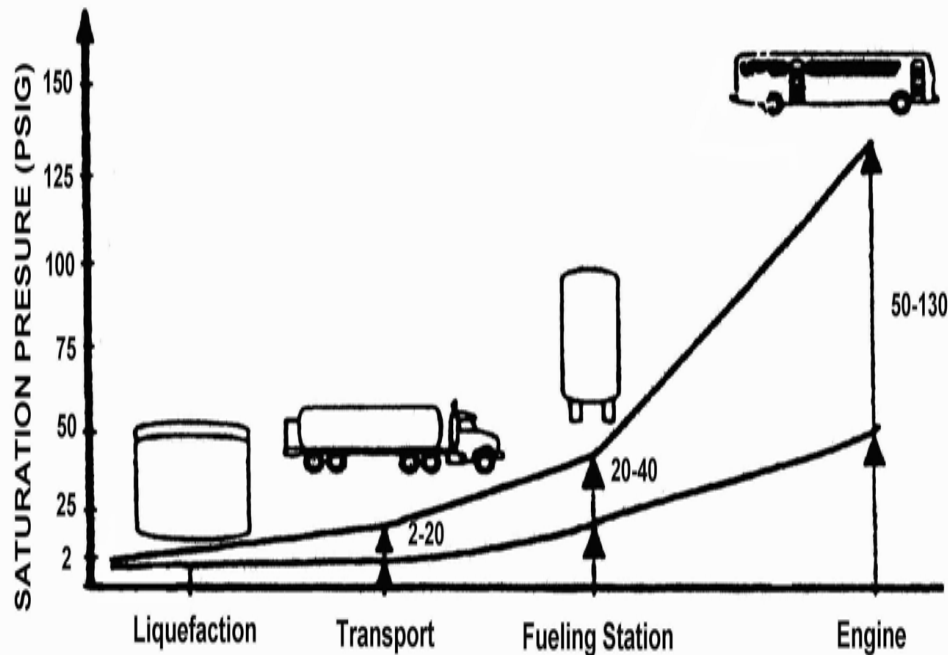
2.3 gal LNG per gallon Diesel
or more

Use it or Lose it



- “C” is the effective thermal conductance of the piping and station storage tank
- Fuel losses depend on the size of the fleet, station design, and type of onboard fuel tank
- Fleet sizes of more than twenty are needed in this example
- One alternative to atmospheric venting is the use of a gen-set

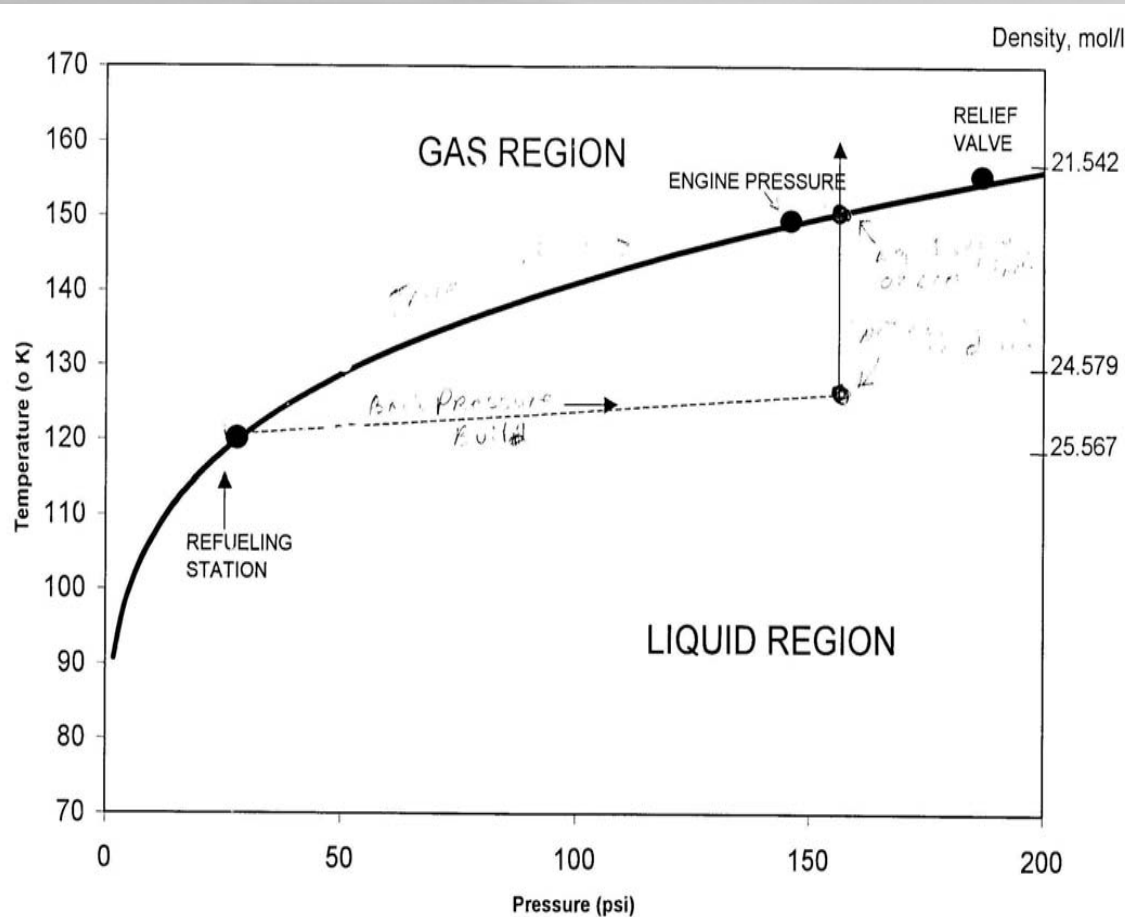
LNG Infrastructure



- Sources of LNG are from the pipeline, imports, stranded gas, and landfills
- The temperature of the LNG will continually increase from the liquefier to the vehicle
- Hence the pressure, density, and composition of the LNG will also continually change
- These changing conditions make establishing SAE-Best Practices very difficult

Why is LNG Problematic?

Saturation Liquid Curve for Natural Gas



- Problematic because it's a cryogenic fluid mixture that changes with time
- Keeping the LNG cold limits the changes
- The onboard fuel tank determines the LNG allowable temperature
- Tests are planned at OCTA to see if one can use sub-cooled LNG without vapor collapse

Vapor collapse delivery system

Advantages

- Single line fill
- No onboard pressure build device
- Higher heat leak rates tolerated

Disadvantages

- Lower onboard fuel density storage
- Connectors are at higher pressures
- Susceptible to weathering
- Requires an economizer valve
- Can experience large pressure changes between engine and tank
- Susceptible to uneven withdraw from multiple tanks
- Can experience incomplete fill

Vapor return

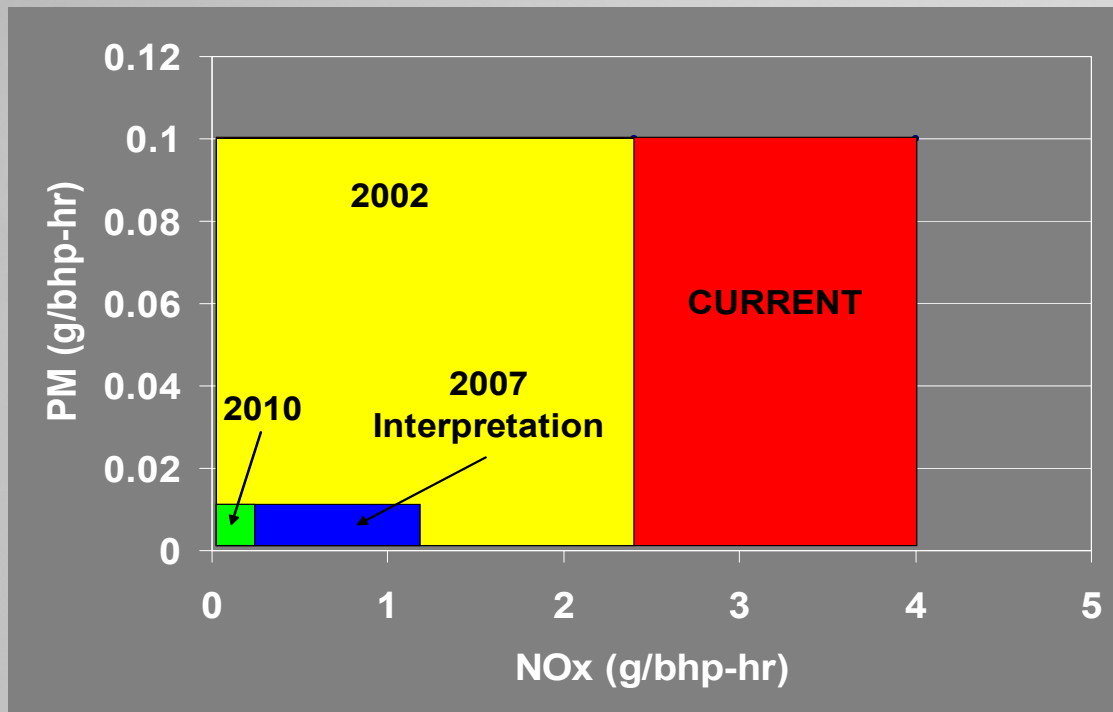
Advantages

- Connectors are at lower pressures
- No weathering problems
- No atmospheric venting of vapor
- Higher onboard fuel density storage
- Uniform pressure drop between tank and engine
- No economizer valve
- Compatible with second stage heat exchanger
- Complete refill

Disadvantages

- Two line connection
- Requires either a gen-set or access to pipeline
- Requires an onboard pressure build (conditioning) device or pump
- Potential for vapor collapse
- Requires a very low heat leak rate tank

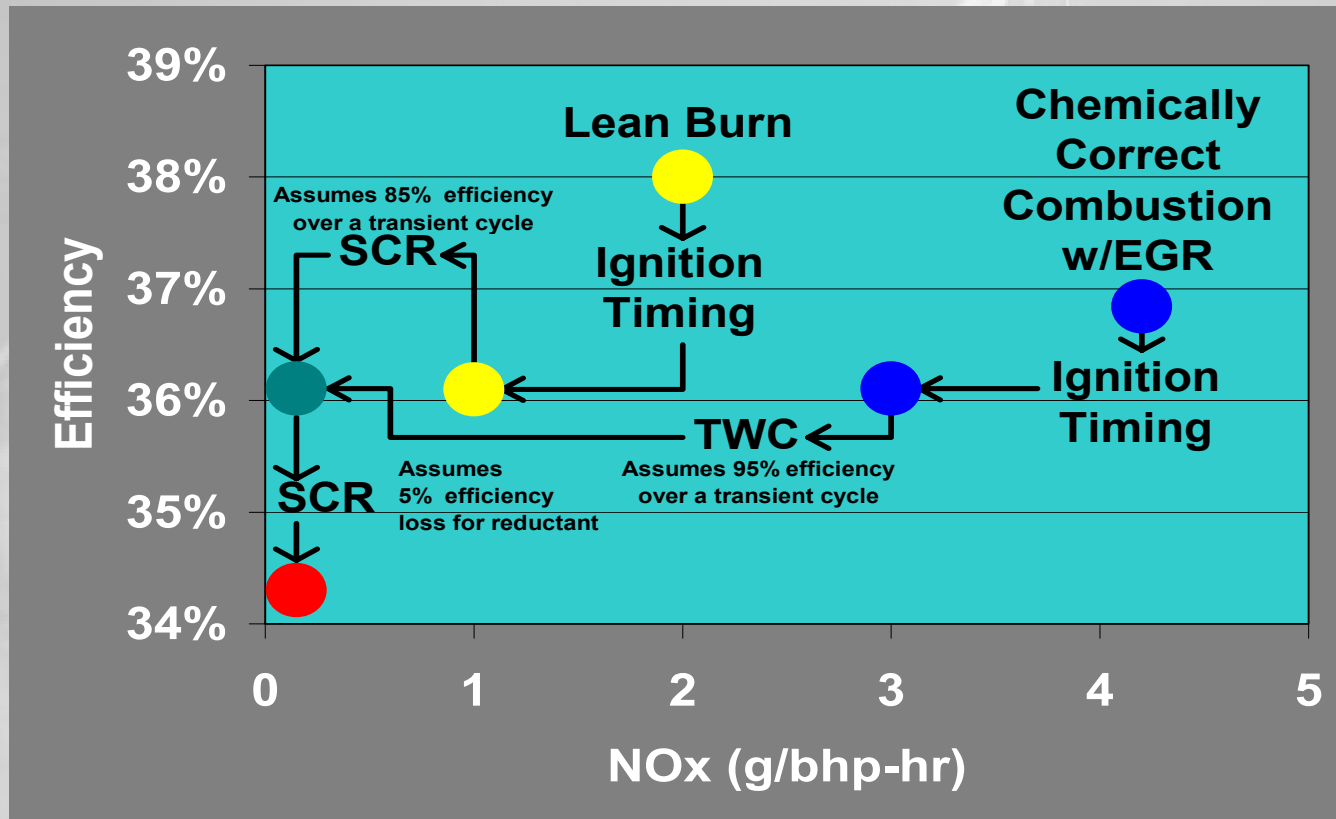
What is the Future of LNG?



- The future is good, IF there is a business case which requires fair taxation and supplies of low cost fuel
- The 2007 NGV(s) will close the increment vehicle cost and fuel economy gaps

Are high-efficiency/durable engines needed?

Yes, a 37% efficient and 300,000 miles service life NG engine will beat the 2007 diesel and make the business case for LNG



What are the Conclusions?

- **Learn from mistakes and let the market decide**
- **Current LNG tax situation is a mess**
- **Gen-sets are needed on LNG refueling stations**
- **Seek political support in the near-term**
- **Gain support by demonstrating markets after 2007**
- **Off-road and stranded gas markets have potential**